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Direct Absorptivity Measurements of Metallic Powders Under 1-Micron Wavelength Laser Light

S. Wu, I. Golosker, M. LeBlanc, S. Mitchell, A. Rubenchik, J. Stanley, G. Gallegos

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Disclaimer

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Lawrence Livermore National Laboratory

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Abstract

- We report on absorption measurements of stainless steel powders illuminated by 1-micron light. Modeling of laser interaction with powders for various applications requires knowledge of absorption coefficients for commercially available materials and powder distributions. A simple method is developed for the direct calorimetric absorptivity measurements. Samples with thin layer of powder on thin Ta foil are uniformly irradiated using a diode-array laser emitting at 975 nm. Small thicknesses provide temperature uniformity across the sample. Temperature is monitored by thermocouples and IR camera. A scheme removing the effect of convective and radiative losses is implemented. Results for several layer thicknesses are presented.

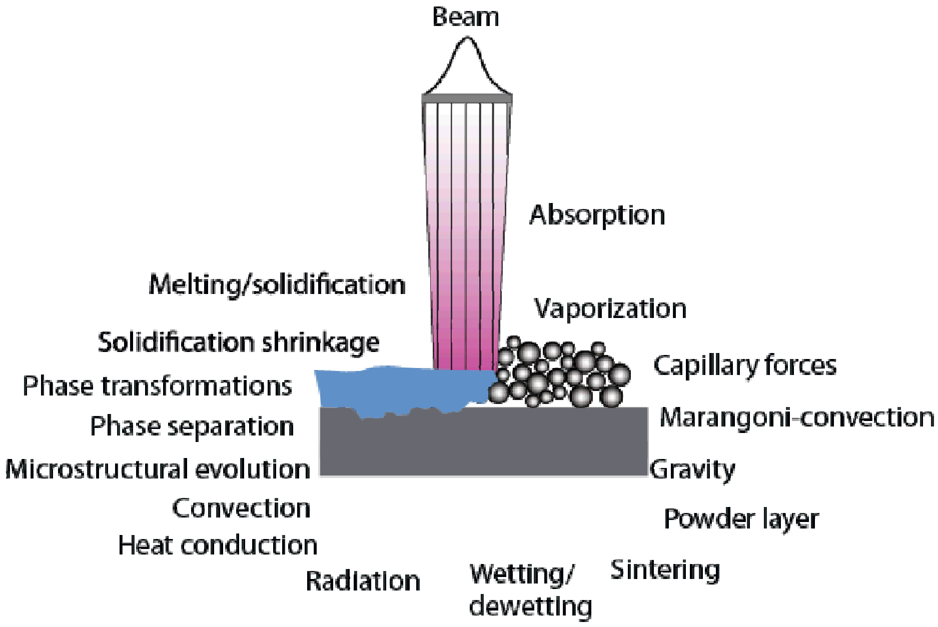
Laser radiation absorption is an important part of the complex physics of additive manufacturing process

Needed:

- Adequate absorption description is required for comprehensive process modeling.
- Models of effective media are not applicable.

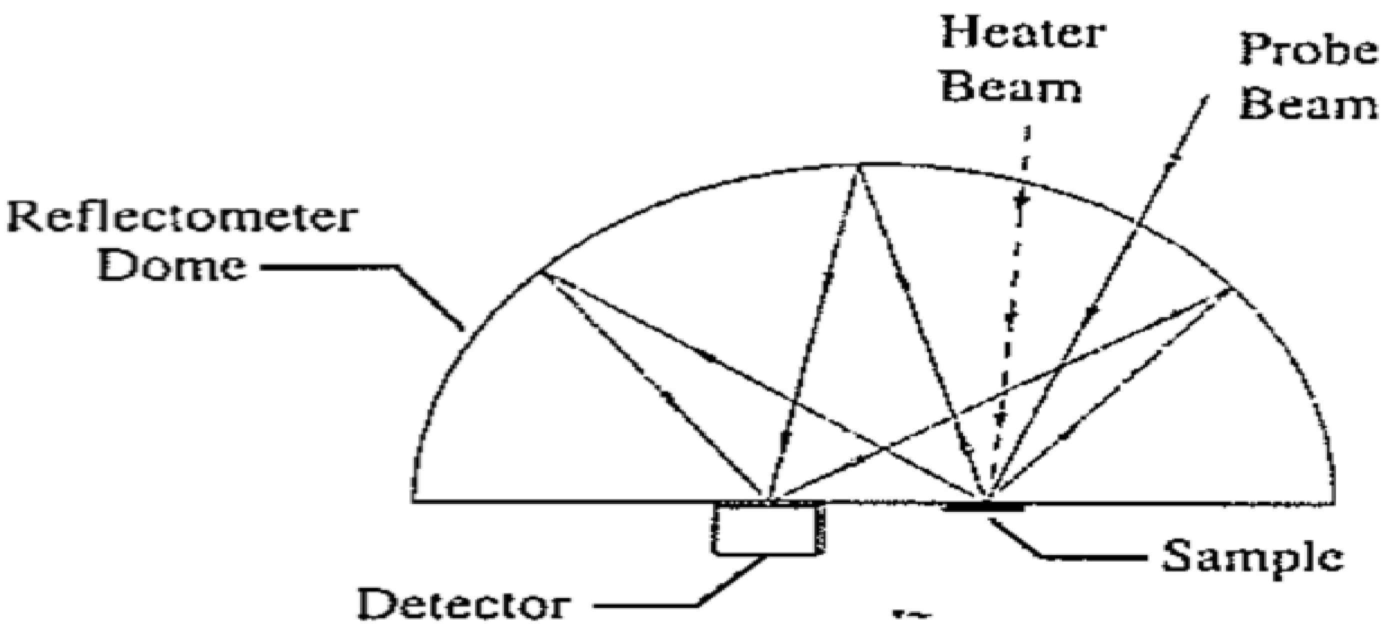
Approach:

- We have used direct absorptivity measurements, taking into account thermal losses and temperature-dependent material properties



This is the first direct absorptivity measurement of powders under laser light

Existent measurement scheme is expensive and doesn't work at elevated temperatures

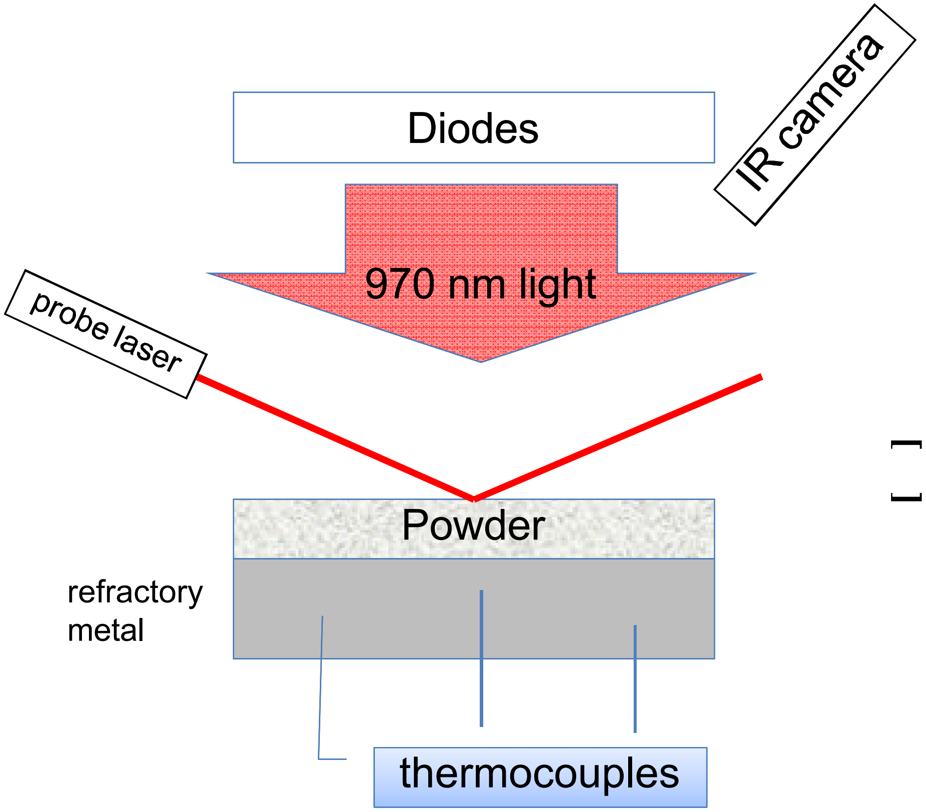


Freeman, R. K., Rigby, F. A., and Morley, N. "Temperature-Dependent Reflectance of Plated Metals and Composite Materials Under Laser Irradiation," *J. of Thermophysics and Heat Transfer* **14**, 3, 2000.

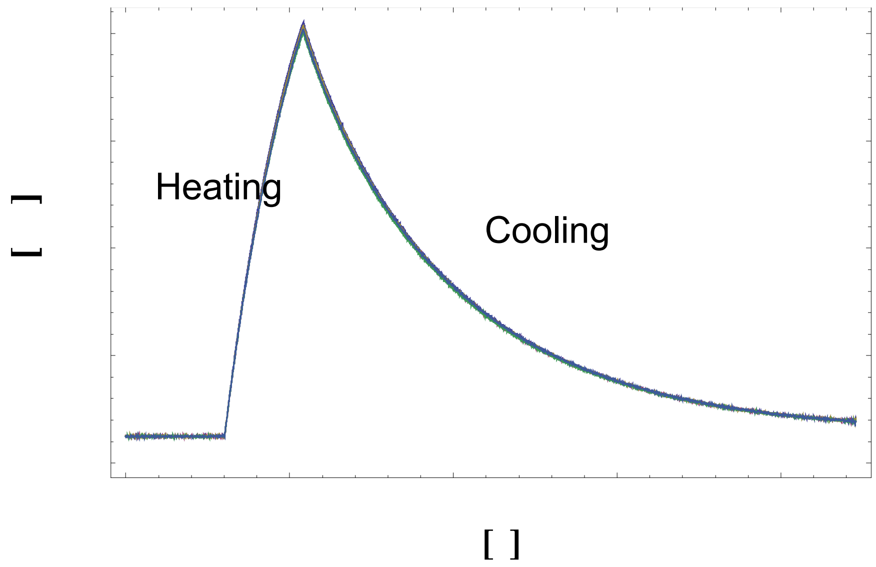
U.S. Air Force Research Laboratory reflectometer

- Does not work well at elevated temperatures
- Difficulty in isolating thermal radiation
- Complex and expensive to implement

Scheme and Idea



Few thermocouples data showing nearly equal temperatures



1. Diodes can provide uniform irradiation over sample
2. At low intensity, thermal diffusion quickly equilibrates temperatures across the thin samples

Powder absorptivity

- Absorptivity can be found from the relation

$$\left(\rho_1 c_1 d_1 + \rho_2 c_2 d_2\right)\frac{dT}{dt} = A(T)I - Q(T)$$

powder — substrate — thermal losses (convective & radiative)

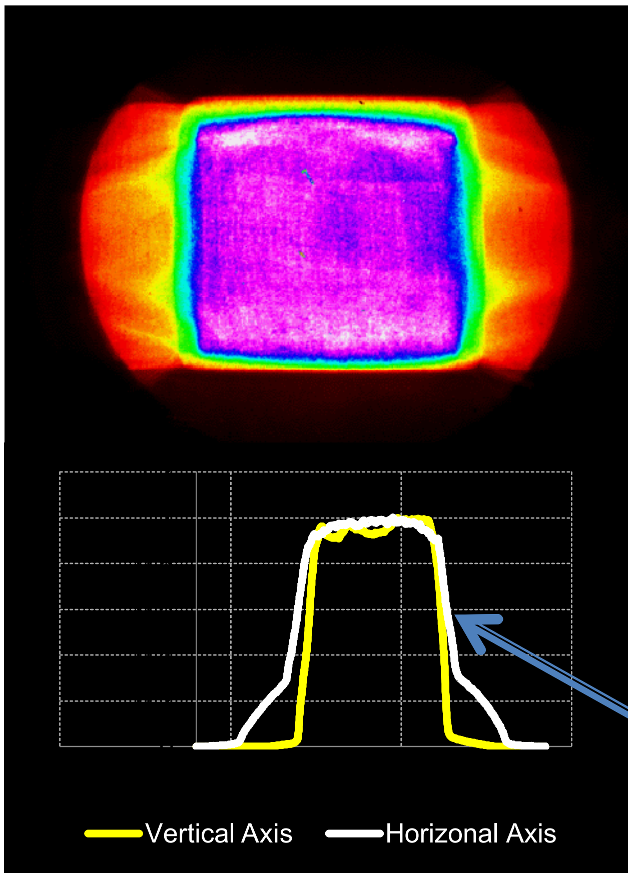
ρ – density
c – specific heat
d – thickness

- Measurement during the cooling provides the info about losses. Given the temperature dependent material parameters, we can determine the temperature-dependent absorptivity by analyzing temperature data in the heating and cooling periods.

- We will be able to apply the same method to powders of different material and composition, and at temperatures up to their melting points and above.

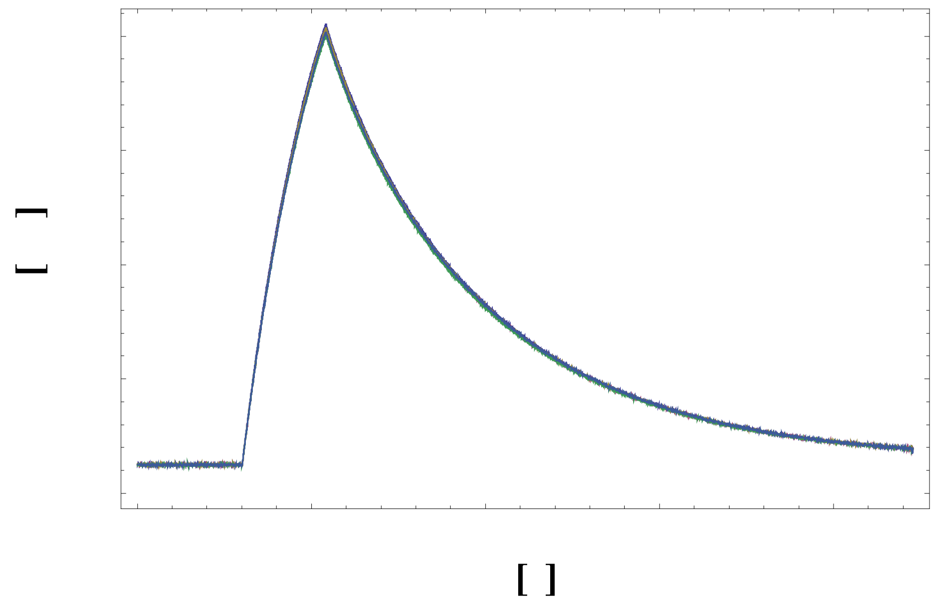
Prior experiments demonstrate uniform sample irradiation from diodes

Diodes light pattern

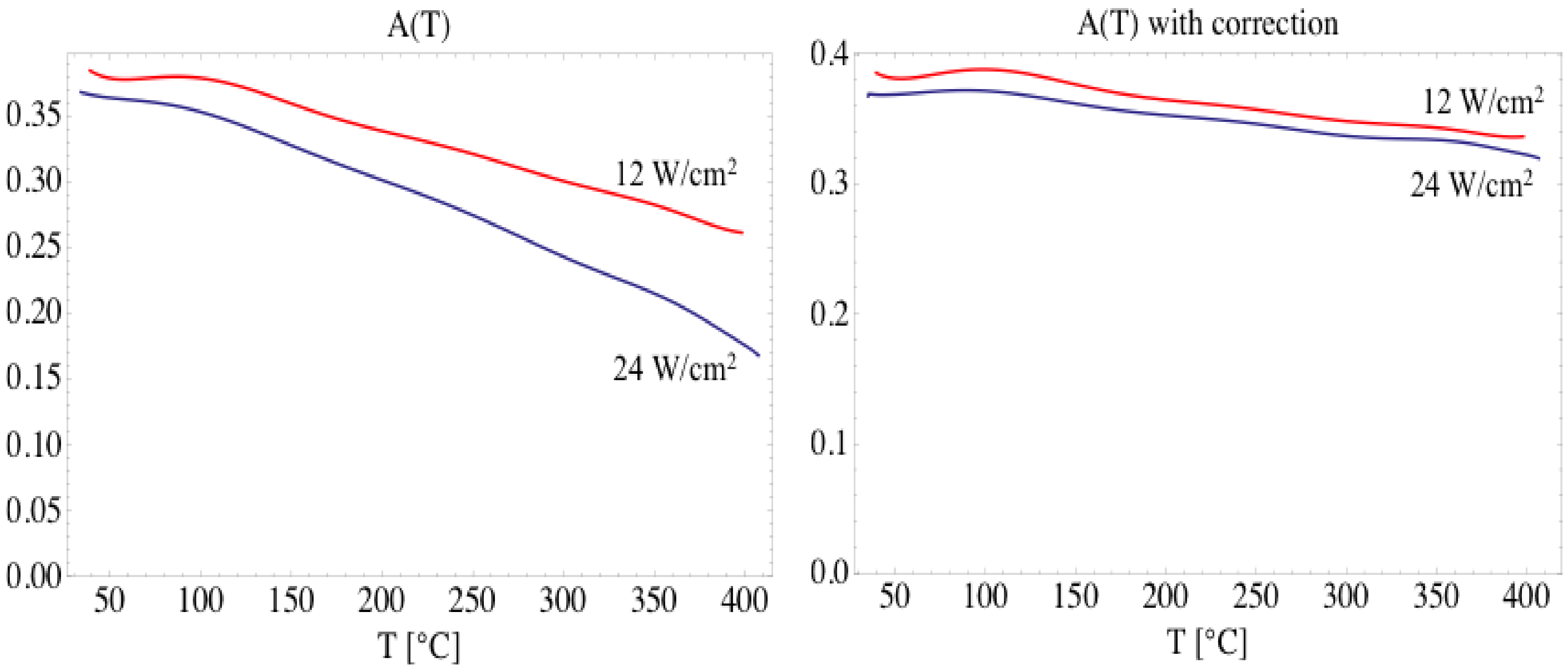


Intensity cross-sectional cut

Few thermocouples data showing nearly equal temperatures. Data for 5 thermocouples in different point merges on the graph.



We are able to eliminate the thermal losses effect



Absorption data before (left) and after (right) removal of thermal losses

Prior absorptivity measurements on metals

6061 aluminum

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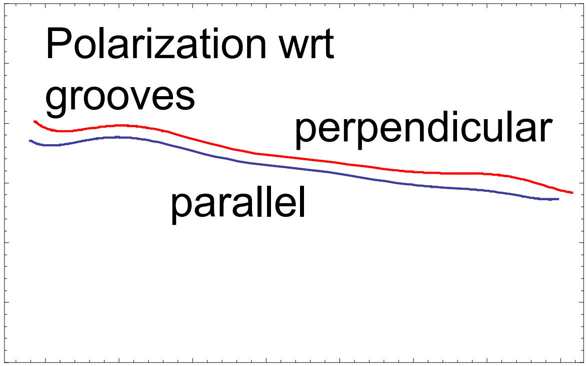

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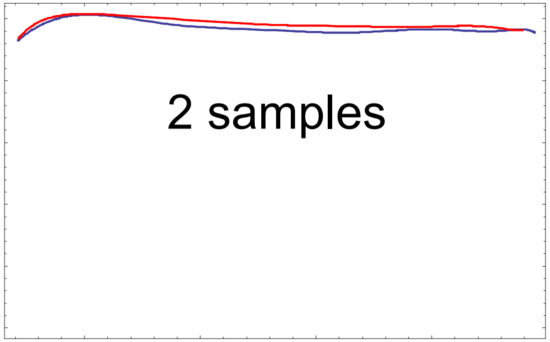
Measurements were done on industrial grade samples.

Cold roll Al samples have a directional groves resulting in polarization dependence.

We developed a special numerical procedure Improving the accuracy of data processing

6-4 titanium

( )



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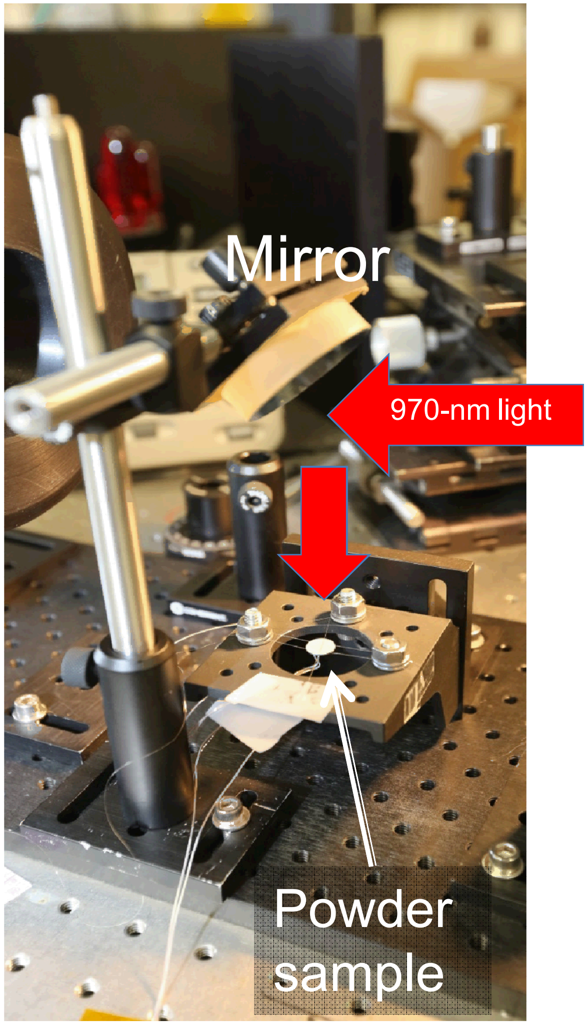
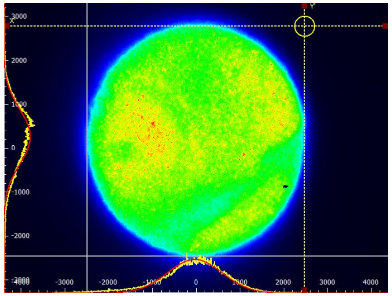
Results summary

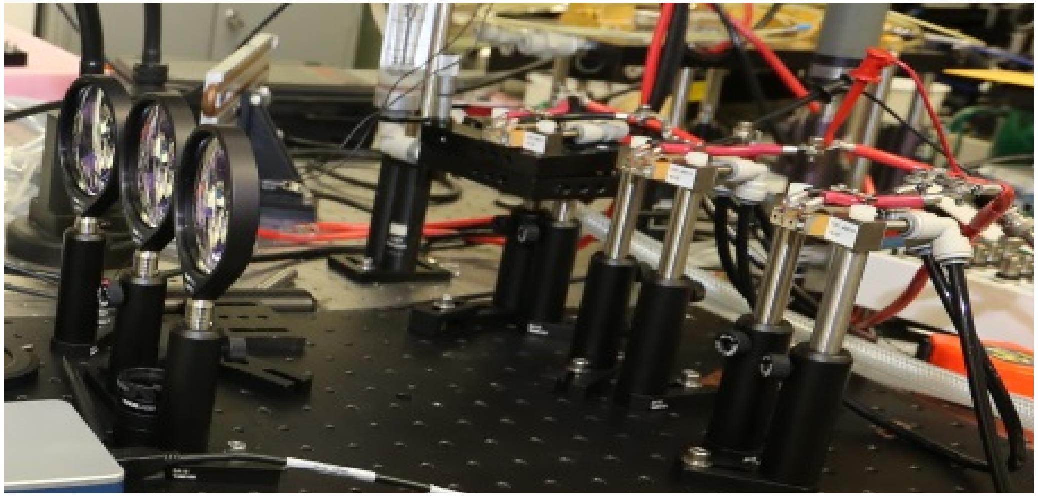
Metal absorptivity	0.8 µm	1 µm
Al	0.35	0.2
Ti	0.5	0.5

Experiment setup



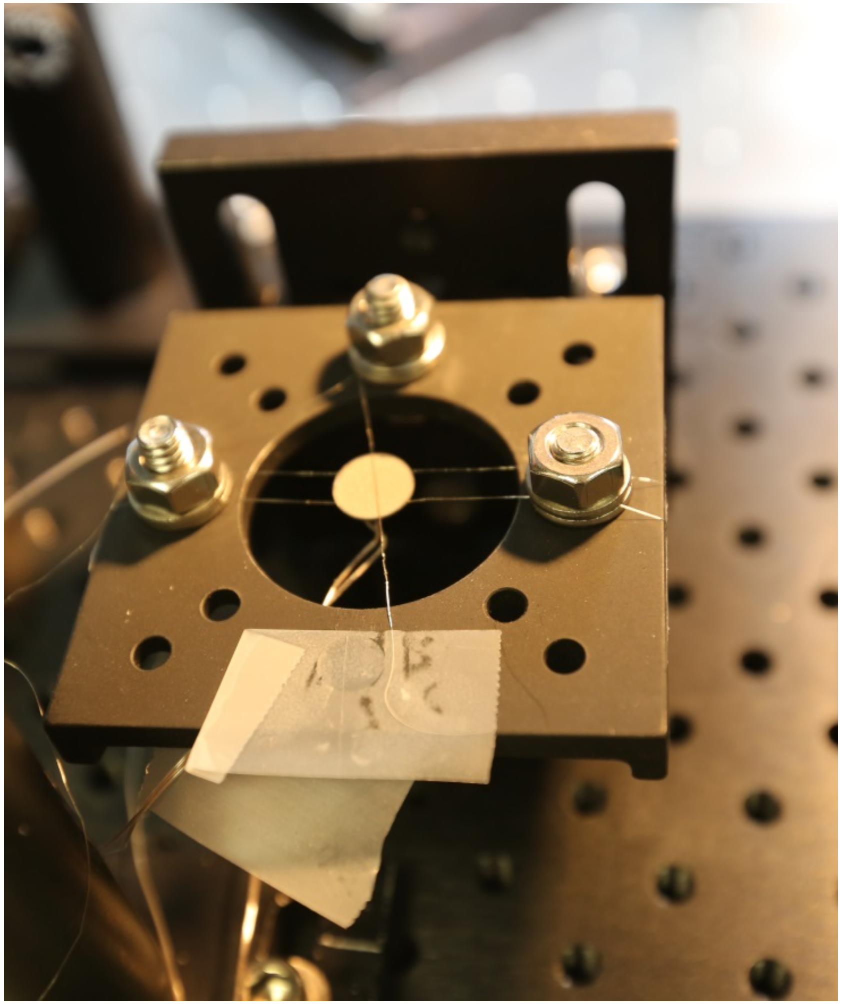
3 VCSEL arrays produce a 1 cm diameter laser spot

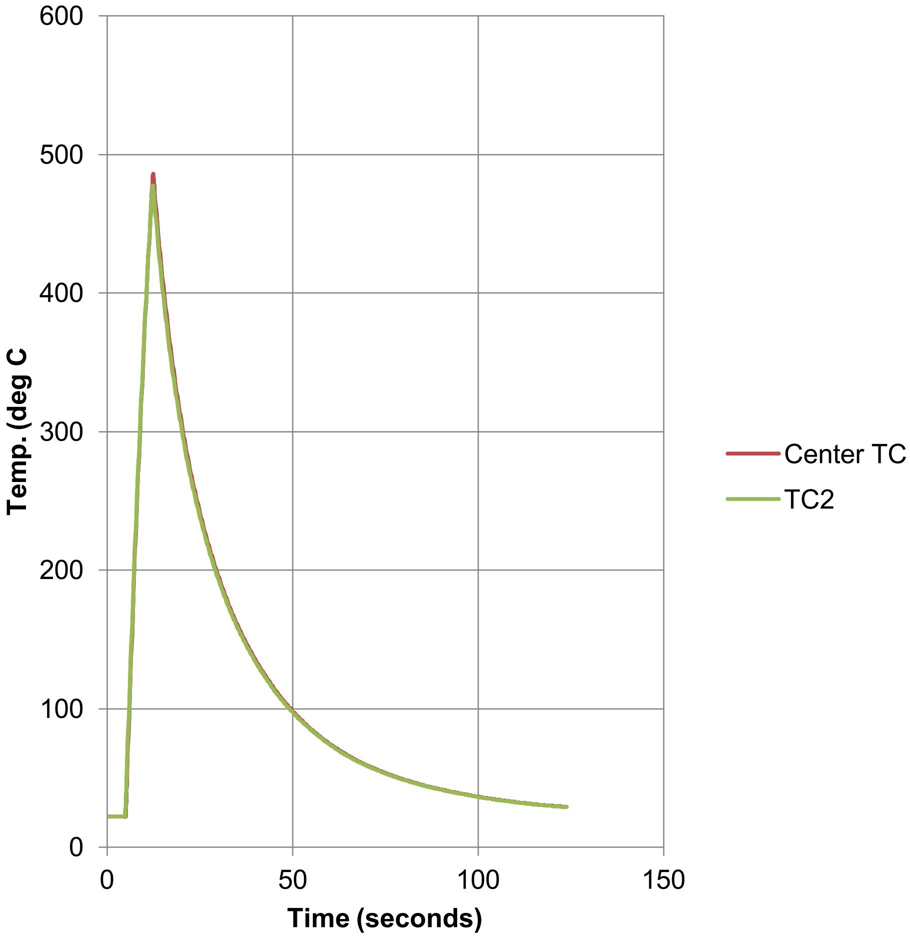


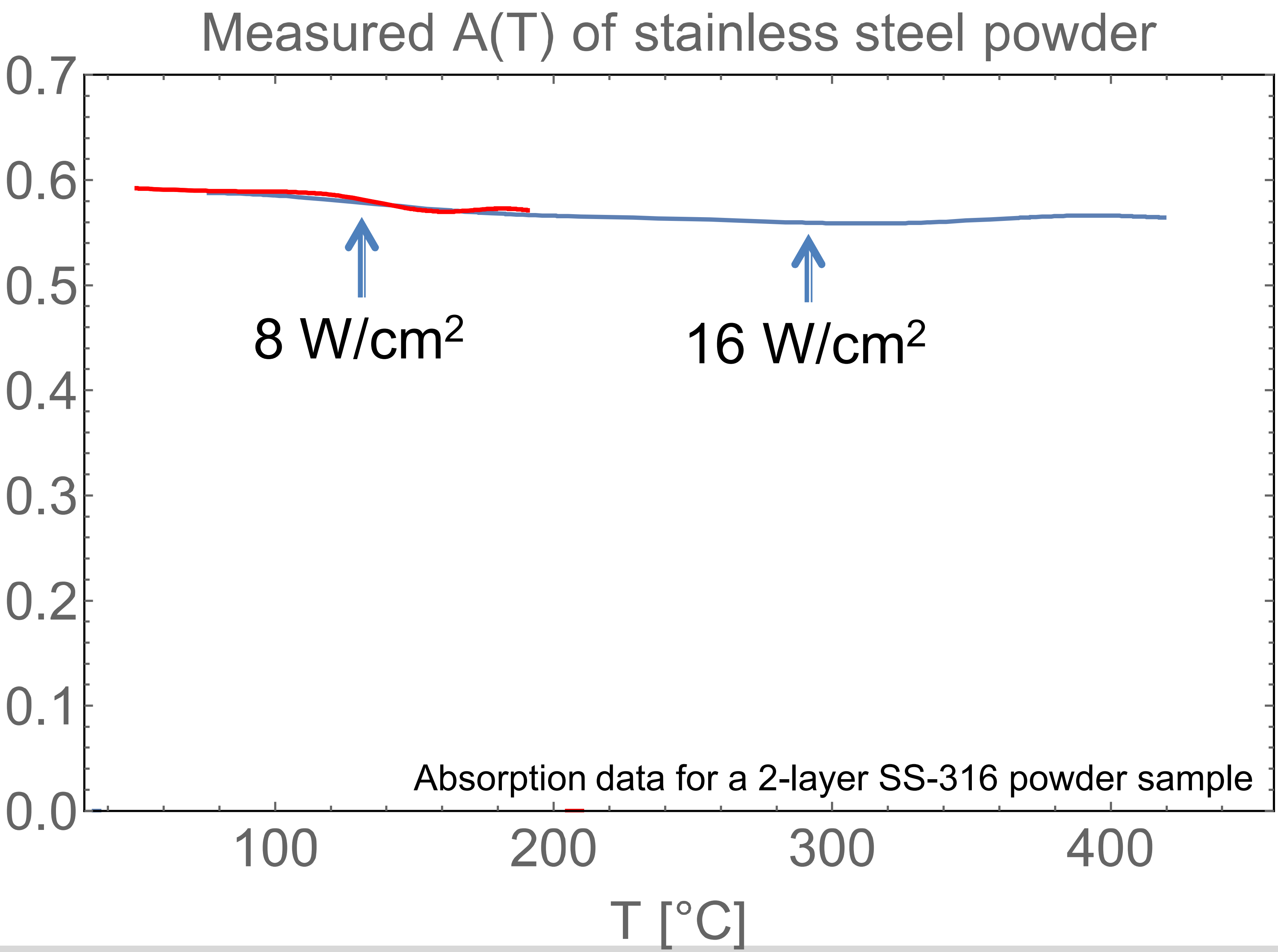


Thermocouple sensors gives absorptivity of sample under irradiation

Experiment demonstrates temperature uniform over the sample

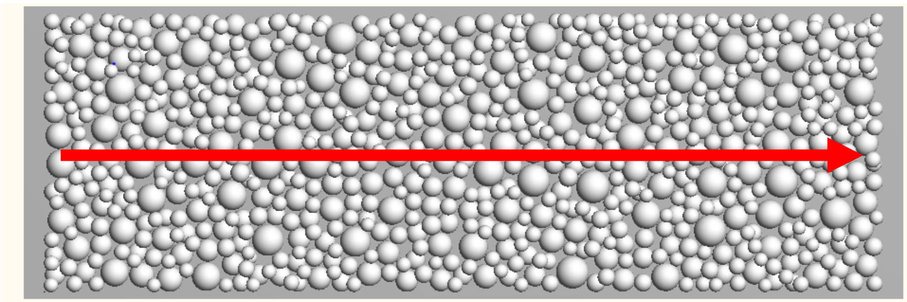


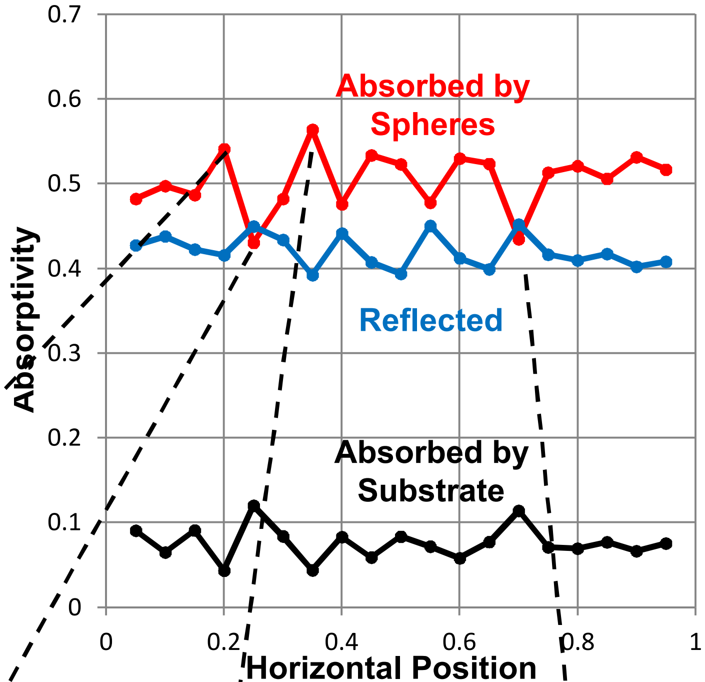



Measured A(T) of stainless steel powder
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
8 W/cm2
16 W/cm2
Absorption data for a 2-layer SS-316 powder sample
100
200
300
400
T [°C]

The results are consistent with ray tracing calculations of absorptivity

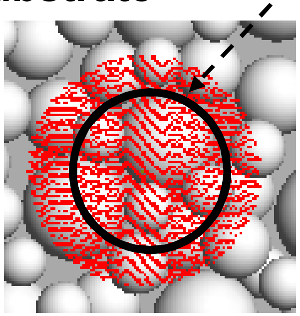
- **Beam absorptivity was calculated along center strip**

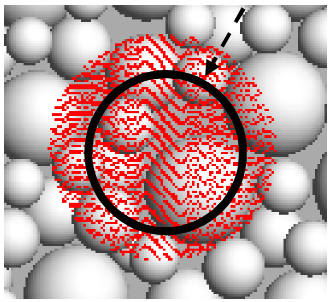


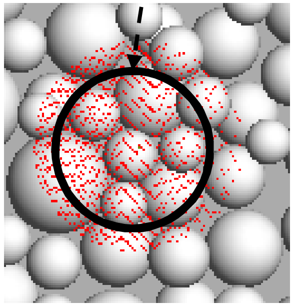


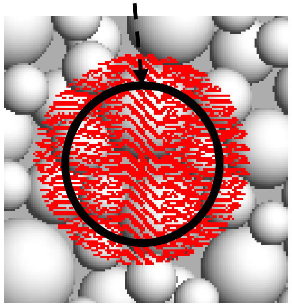
- **Maximum absorption by spheres occurs without visible ‘holes’ in powder**

- **Minimum absorption by spheres occurs when hole allows beam to reach substrate**



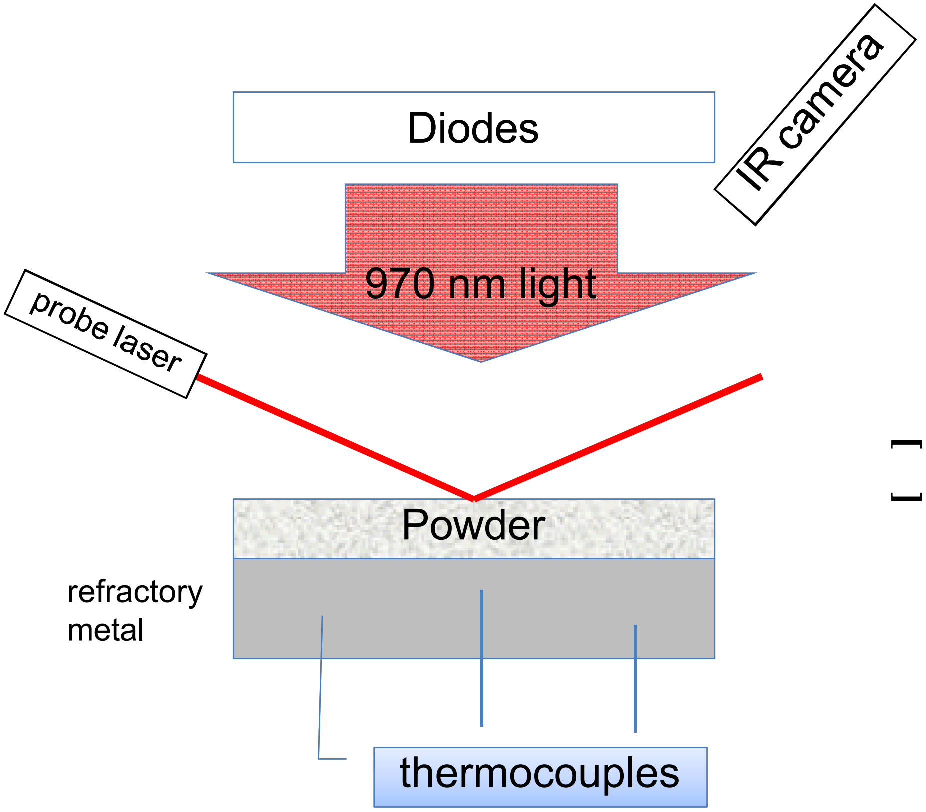






DoubledHalfMaxWidth_powder43microns_thick.txt

Scheme and Idea



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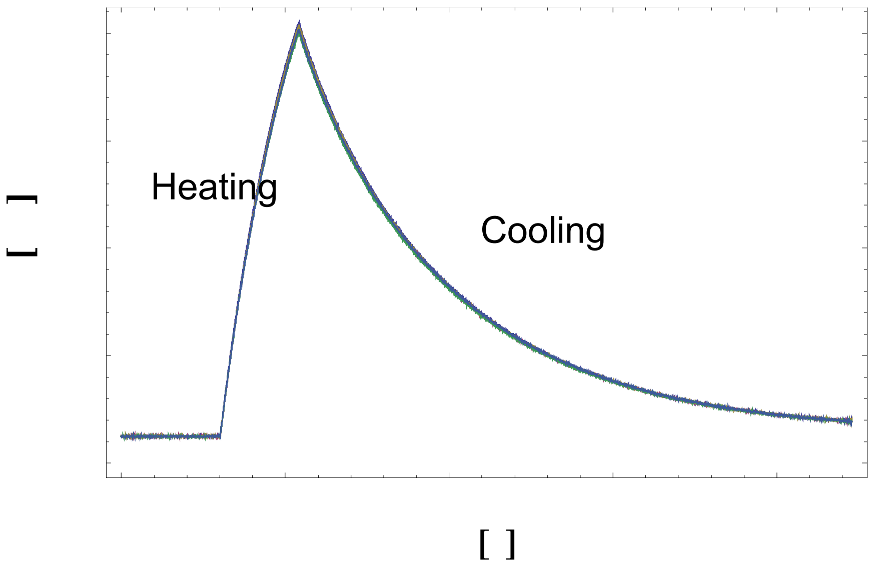

1. Diodes can provide uniform irradiation over sample
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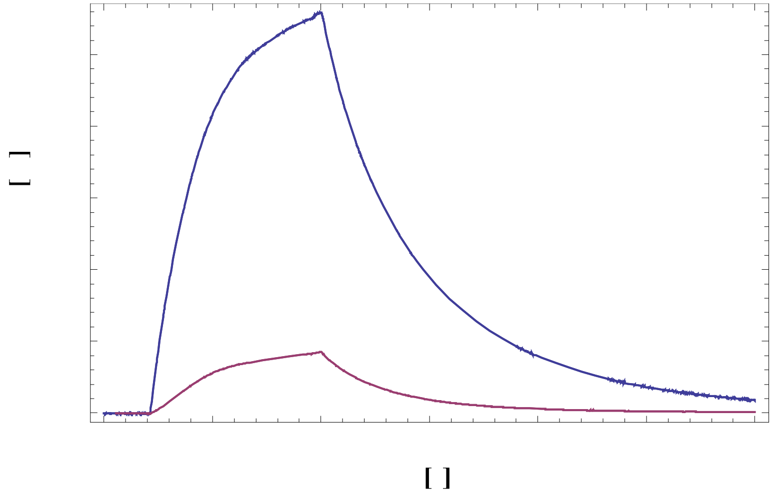
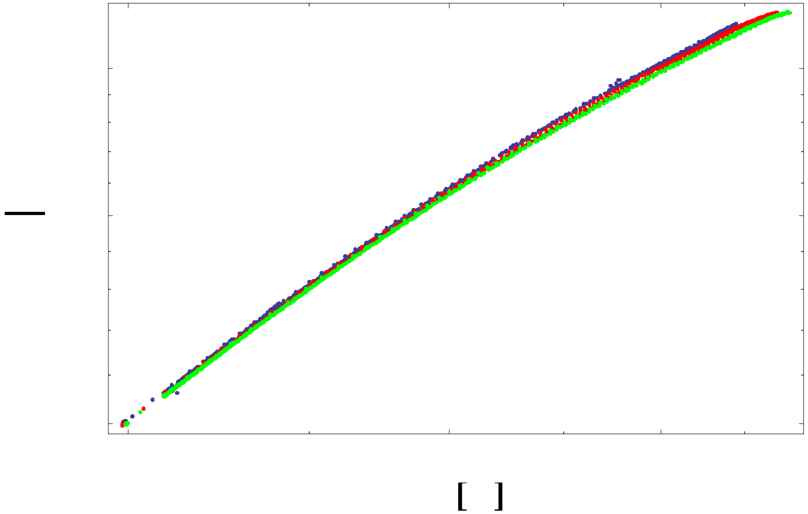
The temperature measurements with thermocouples and IR camera helps calibrate IR camera output.(previous results)

Temperature evolution measured by thermocouple T_{tc} and IR camera T_{c}. FLIR calibration was used.



Ratio of T_{tc}/T_{c} is function of T_{tc} only, for three samples of Al



T_{tc}/T_{c} ratio measured on heating and cooling branches are identical and independent of pump intensity and heating rate. The emissivity is temperature dependent.

Conclusions

- We suggested the new method for direct measurements of the powder absorptivity for different temperatures.
- The absorptivity can be measured for powders of different metals, composition, and thicknesses.
- We developed the method to eliminate the effect of thermal losses
- First experimental data are consistent with ray tracing modeling.